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THE WORLD PHOTOVOLTAIC SCALE: AN INTERNATIONAL REFERENCE CELL CALIBRATION PROGRAM

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ABSTRACT

This paper presents an overview of the World Photovoltaic Scale (WPVS) international reference cell calibration program. The WPVS provides a scale for PV performance measurements that has been established through round-robin calibration of a group of primary reference cells and is traceable to Système International (SI) units. Procedures for recalibration of the reference cell group have been recently devised, along with procedures for admittance and calibration of new reference cells. A reference cell package has been designed that meets the unique needs of the WPVS. It is hoped that the existing WPVS group will eventually be replaced with cells of the new design that have passed an acceptance test procedure.

INTRODUCTION AND BACKGROUND

Previously, we reported the results of the initial calibration of the WPVS reference cell group [1]. For the 20 reference cells calibrated by four national laboratories, an overall 2σ standard deviation of 1.9% was achieved. The calibrations were performed by the four laboratories using their best primary calibration methods, and the high level of agreement has shown that a single primary calibration method dictated by an international standard is not required.

However, a number of drawbacks to the round-robin calibration method were discovered. First, during circulation, the cells are unavailable for long periods of time. Second, circulation involves the risk that the entire group could be lost during shipping. Third, the present WPVS group represents a total of seven different package designs with a wide variety of temperature sensors, cables and connectors, and physical sizes. This diversity causes logistical problems for laboratories performing calibrations. Finally, some of the WPVS cells developed flaws during the PEP'93 circulation, such as bubbles in encapsulation and cracked windows. Therefore, a new WPVS calibration program has been designed to minimize these problems while maintaining the quality of the results. Elements of the program include recalibration of existing WPVS cells and admittance of new cells and laboratories.

CALIBRATION

Procedures have been devised that allow for recalibration of the WPVS group and replacement of existing cells. Lengthy circulations among different laboratories are avoided through periodic recalibration events at single laboratories. These events will be rotated among the laboratories whose data are part of the WPVS average. At the present time, four laboratories meet this requirement: the Japan Quality Assurance Organization (JQA) jointly with the Electrotechnical Laboratory (ETL), the National Renewable Energy Laboratory (NREL), Physikalisch-Technische Bundesanstalt (PTB), and the Tianjin Institute of Power Sources (TIPS).

Recalibration will be accomplished using the following procedure. Each national laboratory traceable to the WPVS will have exactly two cells that are part of the WPVS group. Every 18 to 24 months, a recalibration event will be held to which all traceable laboratories will carry one or two WPVS cells. The recalibration will take place at one of the qualified WPVS laboratories where all available cells will be recalibrated. Following the recalibration event, a meeting of the traceable laboratories will be held to determine the new WPVS calibration values using a qualified running average. A laboratory that does not provide a cell to a recalibration event will no longer be considered traceable to the WPVS.

Addition of new cells or replacement of old cells will be accomplished by calibration at a minimum of three of the qualified WPVS laboratories prior to a recalibration event. Following the informal circulation, the new cells can then be brought to the next recalibration event at which time they will be considered for inclusion in the WPVS group.

Although circulation of the entire WPVS group will not be used for recalibration, intercomparisons of other groups of reference cells will still be an important part of the WPVS. These intercomparisons will be used to gauge each laboratory's performance, and to admit new laboratories into the WPVS average.

WPVS REFERENCE CELL PACKAGE

The new WPVS reference cell package was designed to minimize the problems encountered during the PEP'93 intercomparison and to meet the following goals:

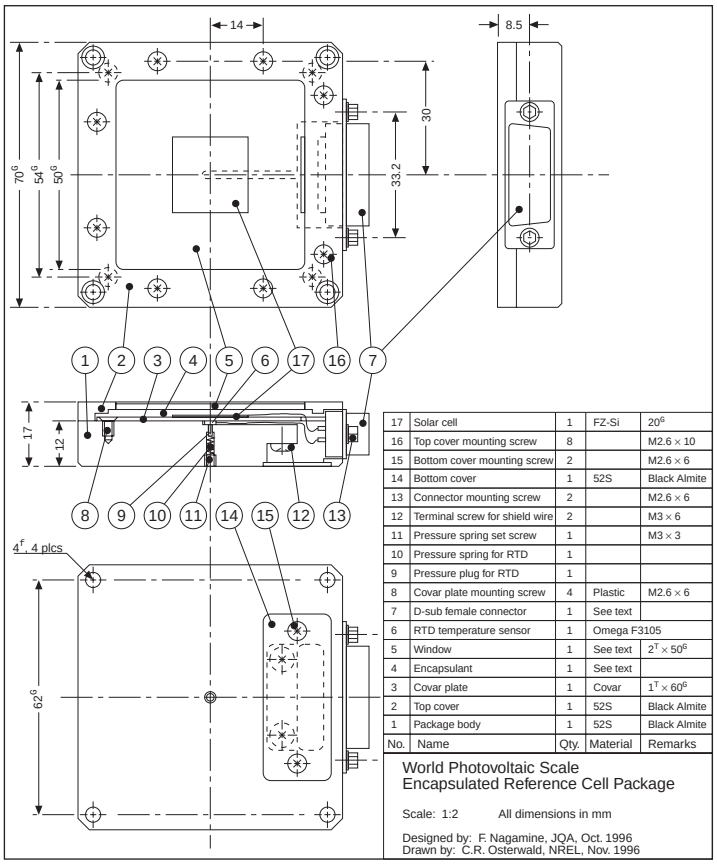
- Adhere to IEC 904-2, section 9.3 [2]
- Total package height ≤ 17 mm
- A 20×20 mm monocrystalline float-zone Si solar cell
- Detachable cables using a female connector on the package side
- Standardized mounting holes
- Silicone, epoxy, or EVA encapsulation
- Durable, smooth front window
- Standard temperature sensor
- Solar cell electrically isolated from the package
- Minimum thermal mass
- An electrically and thermally conductive case
- Black exterior and interior surfaces
- Permanent identification markings
- A flat rear surface without protrusions
- Active cooling, if used, detachable from the body.

Fig. 1 shows the design that was developed from these goals, and Fig. 2 is the wiring diagram for the package. The design evolved from an earlier Japanese package [3] during a meeting of representatives from national laboratories for the PEP'93. Significant features of the design are the two independent temperature sensors, a 100Ω Pt RTD and a copper-constantan thermocouple, and the 15-pin D-subminiature connector. Having redundant temperature sensors increases the reliability and also allows laboratories to use the sensor type best suited for their individual capabilities. The field of view for this design is approximately 164°, which meets the IEC 904-2 specification [2].

Although the physical package in Fig. 1 is complete and meets the design goals, only the following elements are standardized and must be adhered to—the outside dimensions, the window size and location, the solar cell location, the location and size of the four mounting holes at the corners, and the connector location. The other internal details were designed to be compatible with the existing manufacturing processes used by JQA.

REFERENCE CELL ACCEPTANCE TEST

Prior to calibration and admittance into the WPVS group, new reference cells must pass a comprehensive acceptance test that is intended to screen out unacceptable cells, and to prevent or minimize later problems that might occur during use. The acceptance test is a 12-step process



No.	Name	Qty.	Material	Remarks
17	Solar cell	1	FZ-Si	20^{G}
16	Top cover mounting screw	8		M2.6 × 10
15	Bottom cover mounting screw	2		M2.6 × 6
14	Bottom cover	1	52S	Black Almite
13	Connector mounting screw	2		M2.6 × 6
12	Terminal screw for shield wire	2		M3 × 6
11	Pressure spring set screw	1		M3 × 3
10	Pressure spring for RTD	1		
9	Pressure plug for RTD	1		
8	Covar plate mounting screw	4	Plastic	M2.6 × 6
7	D-sub female connector	1	See text	
6	RTD temperature sensor	1	Omega F3105	
5	Window	1	See text	$2^{T} \times 50^{G}$
4	Encapsulant	1	See text	
3	Covar plate	1	Covar	$1^{T} \times 60^{G}$
2	Top cover	1	52S	Black Almite
1	Package body	1	52S	Black Almite

World Photovoltaic Scale
Encapsulated Reference Cell Package

Scale: 1:2 All dimensions in mm

Designed by: F. Nagamine, JQA, Oct. 1996
Drawn by: C.R. Osterwald, NREL, Nov. 1996

Fig. 1. Physical design of the new WPVS reference cell package.

and is presented in Fig. 3. The results of these tests and characterizations become a part of the cell's calibration and permanent records.

A verification that the cell meets the physical and dimensional requirements is the first step, and requires measurements to be made prior to encapsulation. Following manufacture, a visual inspection is made to find problems such as internal reflections from nonblack surfaces, encapsulant flaws such as bubbles or delamination, illegible identification markings, and broken or scratched windows. To verify that both temperature sensors are functional, the cell is placed in the dark at several temperatures between 10°C and 50°C and the output of the sensors compared.

Light and dark current-voltage (I-V) measurements are performed to detect changes that may occur during a 4-hour light soak in >850 W/m^2 Xe or natural sunlight illumination. Following the light soak, the I-V measurements and the visual inspection are repeated. Because WPVS reference cells must be used in high-speed measurement systems such as pulsed solar simulators, a hysteresis test is used to identify cells that may have problems in such systems.

Lastly, a light instability test is performed to find cells that have I-V characteristics with unacceptably long time constants under illumination. The test consists of measuring current versus time under illumination as the cell is switched between open- and short-circuit conditions.

TRACEABILITY

The total uncertainty of the WPVS average is dependent on the traceability of the individual calibrations to measurement standards, and, ultimately, to the SI system of units. Traceability is especially important because the International Bureau of Weights and Measures (BIPM) adopted a resolution at the 20th Conférence Générale des Poids et Mesures in October 1995, that recommends that agencies "responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programmes are in terms of well-characterized SI units so that they are reliable in the long term, are comparable world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Mètre." This resolution is certainly applicable to photovoltaics, so the WPVS should be traceable to SI units only.

Photovoltaic calibrations involve both electrical and radiometric measurements. Electrical traceability is routinely achieved through calibration of instrumentation to SI transfer standards, but radiometric traceability is not as easily attained. Currently, the four laboratories in the WPVS average are traceable as follows: (1) JQA/ETL—Commission Internationale de l'Eclairage (CIE) standard lamp; (2)

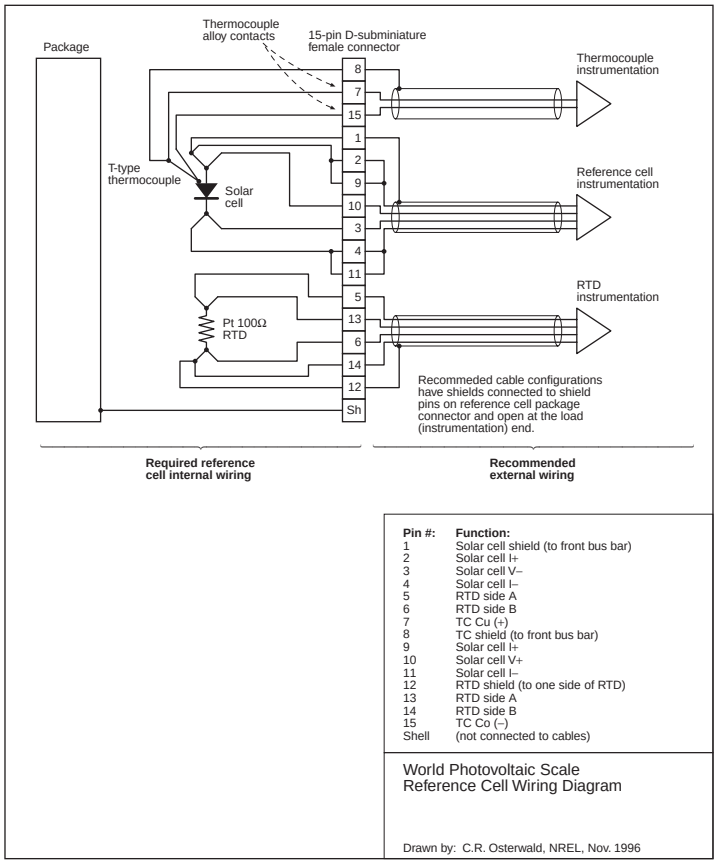


Fig. 2. Wiring diagram of the new WPVS reference cell package.

NREL—World Radiometric Reference (WRR) absolute cavity radiometer; (3) PTB—standard detectors traceable to SI units via cryogenic radiometers, and; (4) TIPS—National Institute of Metrology standard lamp. Some of the apparent disparity of traceability has been relieved by a recent comparison of the SI radiometric scale against the WRR. The comparison showed that the WRR is very close to the SI radiometric scale, at -0.0005 ± 0.026%, as realized by cryogenic radiometers [4].

CONCLUSIONS

Building on the excellent agreement from the calibration of a group of reference cells by several national laboratories, an international program for reference cell calibrations has been developed that does not require standardization of a single calibration procedure, nor time-consuming round-robin circulations. The program includes a new reference cell package designed to facilitate calibration at different laboratories. It is recommended that the details of the calibration program and the new package design be considered for standardization by the International Electrotechnical Commission. Also, it is desirable that new reference cells manufactured according to the WPVS design will become commercially available in the near future.

ACKNOWLEDGMENT

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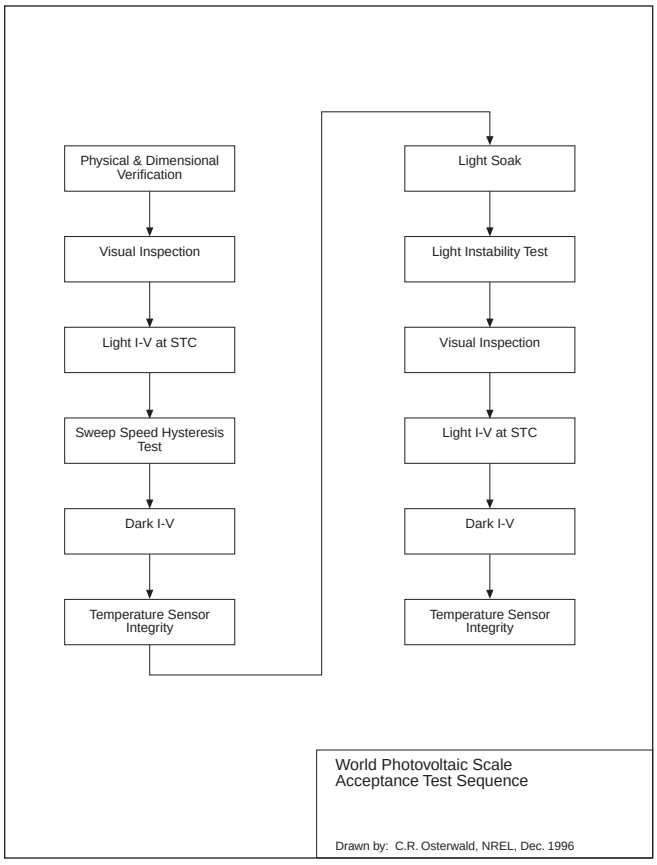

Fig. 3. Flow sequence of the WPVS acceptance test procedure.